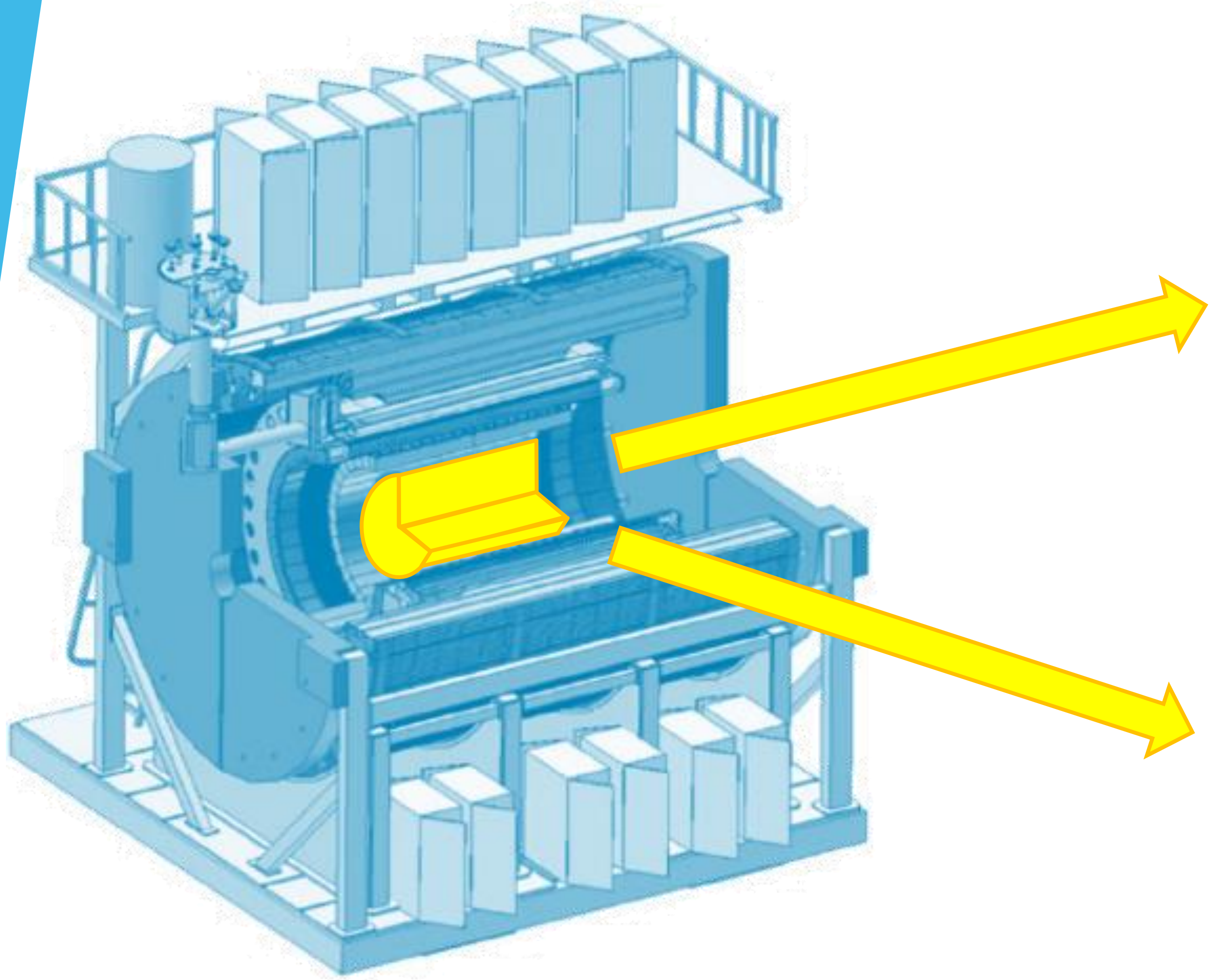
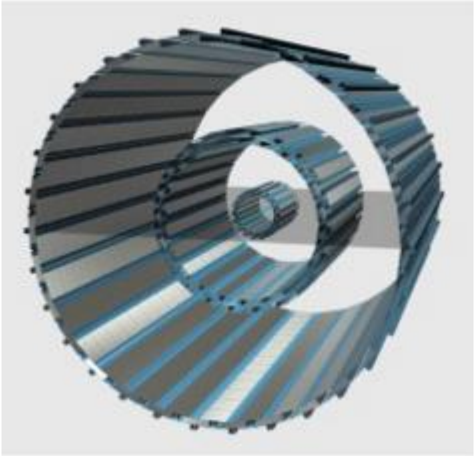
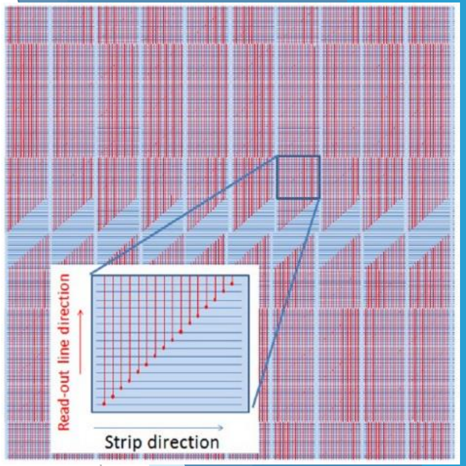
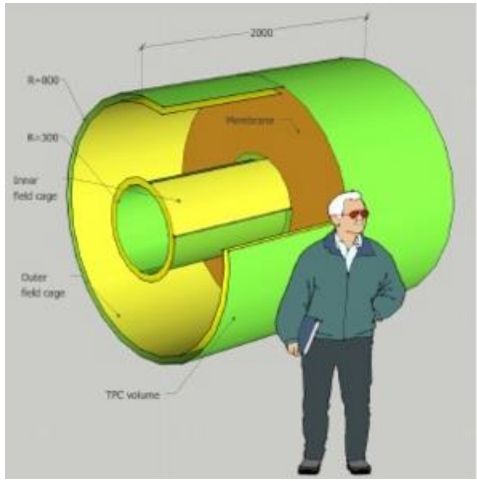
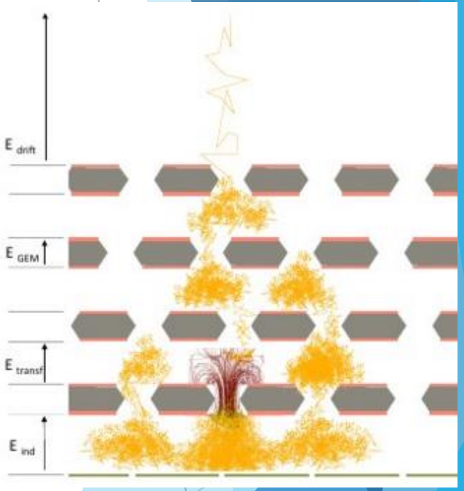










sPHENIX Tracking System

TK Hemmick

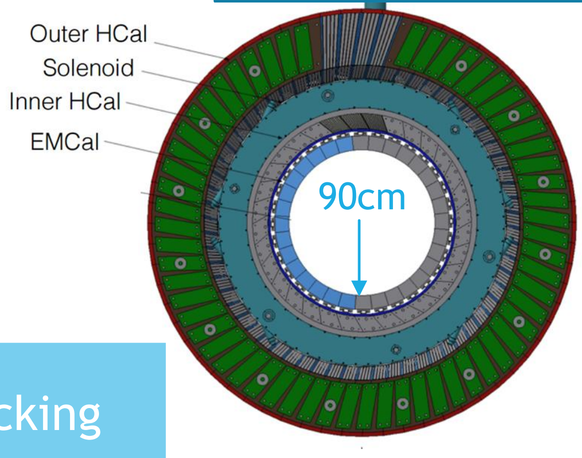
Detector Specifications

"…we anticipate that the features and experience gained with this device might provide the basis for a "day-1" detector at a future EIC, independent of where the new facility will be sited. It is envisioned that this new collaboration will consider the possible evolution toward such a detector as part of its mission."

--Berndt Mueller

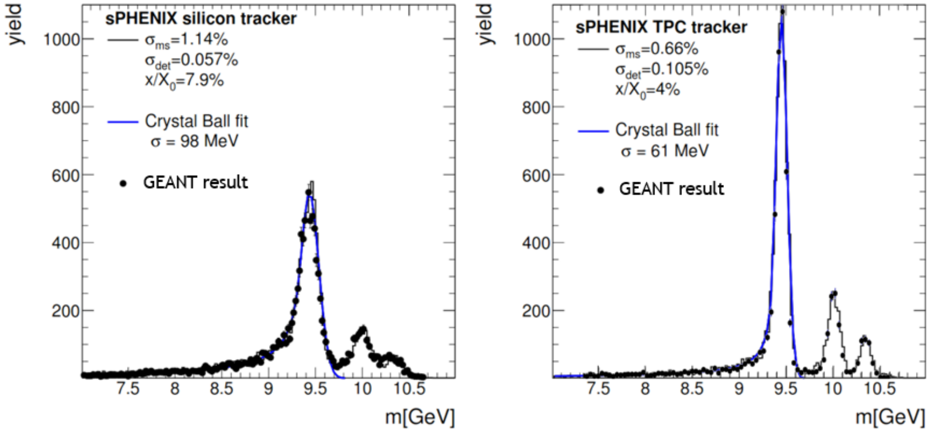
Entertaining options requires more work but generates the necessary flexibility.

- Mechanical Constraints (magnet/EMCal-driven)
  - EMCal Mechanical constraint @ r=90cm.
  - Physics = coil aspect ratio: $|\eta| < 1.1$ or $Length \approx Diameter$
    - Current Tracker Confining Volume: Length = Diameter = 160cm.
- Physics program accomplished via two toughest constraints:
  - Mass resolution sufficient to resolve Upsilon States.
    - $\boldsymbol{\sigma_m < 100\ \frac{MeV}{c^2}\ @\ m \approx 9\ \frac{GeV}{c^2}}$ ← Outer Tracking
  - DCA Resolution sufficient for tagging heavy flavor secondary vertices.
    - $c\tau(D) = 123\ \mu m;\ \ c\tau(B) = 457\ \mu m$
    - $\boldsymbol{\sigma_{DCA} < 100\ \mu m}$ ← Inner Vertex
- Environmental constraints:
  - Central Au+Au multiplicity @ full RHIC Energy.
  - Full RHIC-II Luminosity (100 kHz raw, 15 kHz w/in vertex)



Mechanical Constraint

Physics Constraint



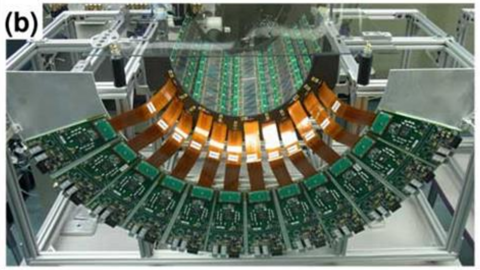
Description of Subsystem Options

- Inner Vertex Detector ($\sigma_{DCA} < 100\ \mu m$)
  - Reuse existing PHENIX VTX pixel detector & spares.
  - MAPS Technology ($e.g.$ ALICE ITS Upgrade)

- Outer Tracker ($\sigma_m < 100\ \frac{MeV}{c^2}$ @ $9\ \frac{GeV}{c^2}$)
  - Silicon Strip Detector
  - Non-gated TPC (Hybrid means TPC+reuse)

Reuse PHENIX VTX Components

- Momentum Resolution Limited by Multiple Scattering.
- Significant Dead Area (non-working & gaps)

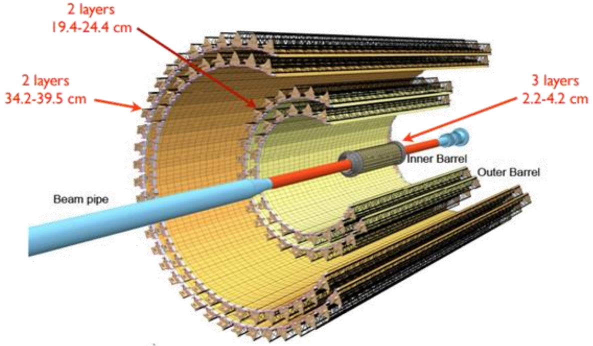


ALICE ITS upgrade detector

All layers composed of pixels.
- Inner three layers: 0.3% / layer
- Outer four layers: 0.8% / layer

Total thickness X/X_0 = 4.1%

Pixel sizes:
inner barrel 20-30 x 20-30 μm
outer barrel 20-50 x 20-50 μm

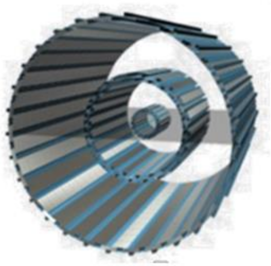


NOTE: Existing PHENIX pixel detector currently achieves 60 μm @ p_T > 2 Gev/c DCA resolution (50 μm evt vertex; 30 μm pixel).

MAPS technology would only improve this due to smaller pixels and less material.

New PHENIX-like Components

- Straightforward technology.
- Fast (no event pileup).
- Multiple-Scat limited.
- Little PID capability



Compact TPC (ala ALICE?)

- Higher momentum resolution
- Smaller Bremsstrahlung tails.
- Leverage ALICE R&D
- PID via dE/dx & neutral V's.

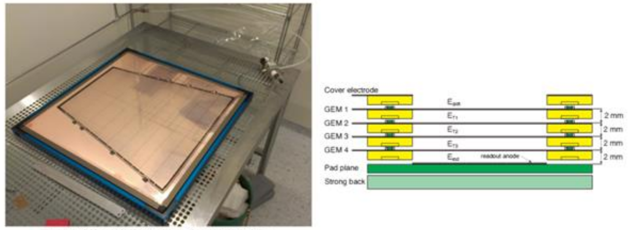


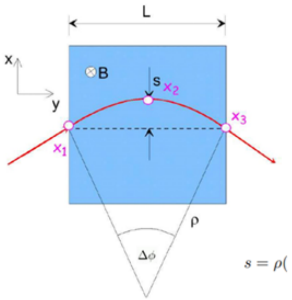
Figure 4.7: Photograph of an IROC GEM foil in the stretching frame.

Comparison requires detailed simulation.

<u>Terminology</u>:
- **Reference:** Reuse + Si-Strip
- **Hybrid:** Reuse + TPC
- Others as indicated

Momentum Resolution-I

Position Resolution:
(Silicon best)

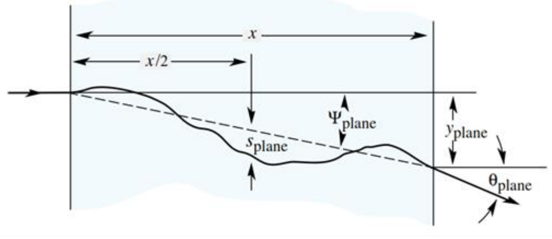


$$s = \rho(1-\cos\frac{\Delta\phi}{2}) \approx \rho(1-(1-\frac{1}{2}\frac{\Delta\phi^2}{4})) = \rho\frac{\Delta\phi^2}{2} \approx \frac{0.3}{8}\frac{L^2B}{p_T}$$

$$\frac{\sigma_{p_T}}{p_T} = \frac{\sigma_s}{s} = \frac{8\sigma_s}{0.3L^2B}p_T$$

$$\boxed{\frac{\sigma_{p_T}}{p_T} = \sqrt{\frac{720}{(N+4)}}\,\frac{\sigma_x}{0.3L^2B}p_T}$$

Multiple Scattering:
(Hybrid better)



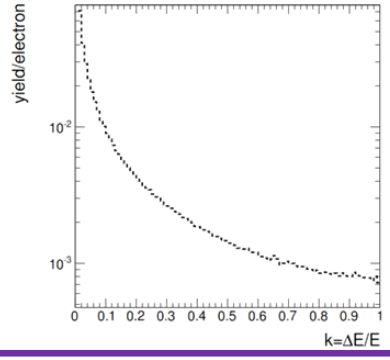
$$\phi_0 = \frac{13.6\mathrm{MeV}}{\beta c p_T} z\sqrt{\frac{L}{X_0}}[1+0.038\ln\frac{L}{X_0}]$$

$$\boxed{\frac{\sigma^{ms}_{p_T}}{p_T} = \frac{0.052}{\beta BL}\sqrt{\frac{L}{X_0}}[1+0.038\ln\frac{L}{X_0})].}$$

3 Dimensions:

$$\boxed{\frac{\sigma_p}{p} = \sqrt{\left(\frac{\sigma_{ms}}{\sqrt{\sin\theta}}\right)^2 + \left(\sigma_{det}\; p\sin\theta\right)^2 + \left(\sigma^{det}_{\theta}\;\cot\theta\sin\theta\right)^2 + \left(\frac{\sigma^{ms}_{\theta}}{\sqrt{\sin_{\theta}}}\frac{\cot\theta}{p}\right)^2}}$$

Bremsstrahlung:
(Hybrid better)



$$k \equiv \frac{\Delta E}{E} \qquad \frac{d\sigma}{dk} = \frac{A}{X_0 N_A k}\left(\frac{4}{3}-\frac{4}{3}k+k^2\right)$$

$$\boxed{N_\gamma = \frac{L}{X_0}\left(\frac{4}{3}\ln\frac{k_{max}}{k_{min}} - \frac{4(k_{max}-k_{min})}{3} + \frac{k^2_{max}-k^2_{min}}{2}\right)}$$

Tracking Systems (Practice)

Momentum Resolution calculated for all options from analytic and full Monte Carlo Simulations

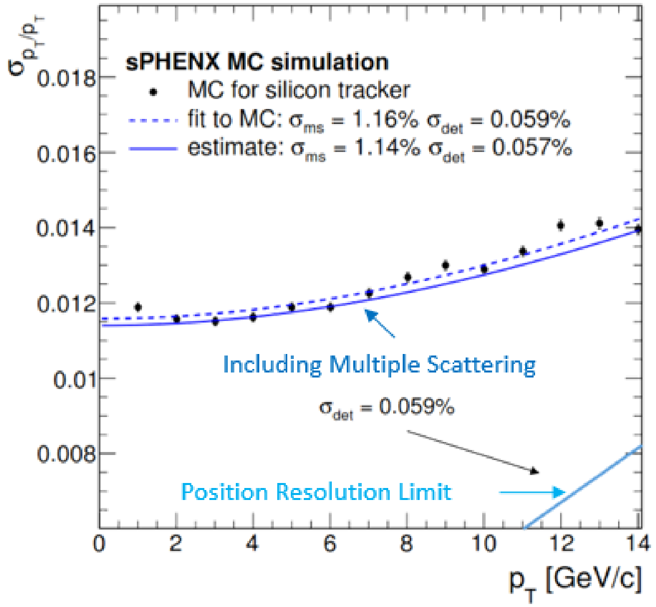
Momentum Resolution-II

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18
S0b	4	8.5	58	9.6	240	1.0	0.18
S1a	5	31.0	58	9.6	240	0.6	1.4
S1b	6	34.0	58	9.6	240	0.6	1.4
S2	7	64.0	60	9.6	320	1.0	6.5

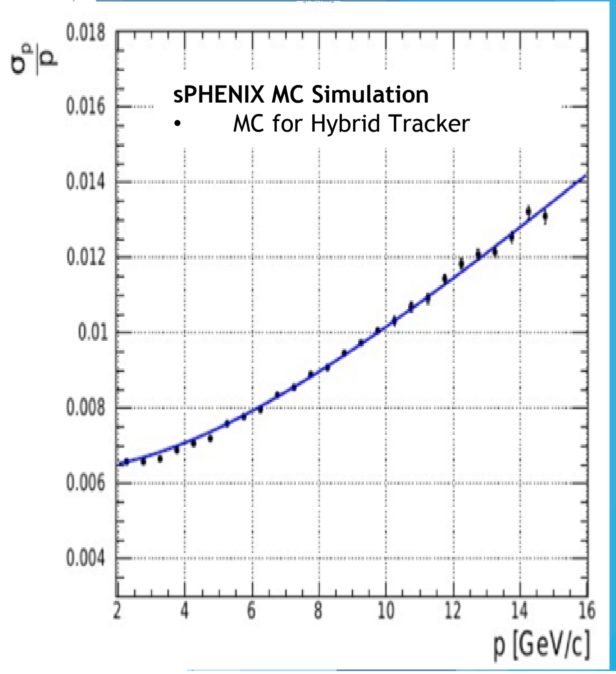
layer	radius (cm)	total thickness % X_0	$\Delta L/L$	c_{ms} (mrad)	σ_{ms} (mrad)
VTX 1	2.7	1.3	0.95	1.8	1.7
VTX 2	4.6	1.3	0.92	1.8	1.7
air	15	0.1	0.73	0.03	0.02
field cage	30	1.0	0.45	1.12	0.5

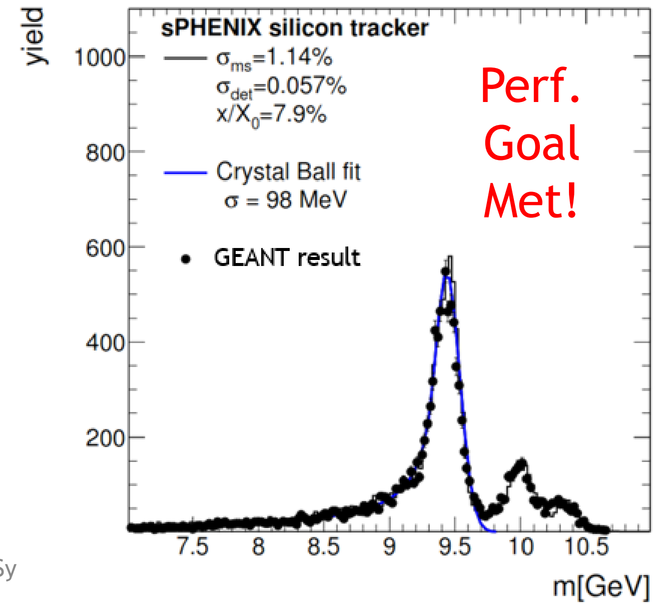
- Analytic and full Geant simulations performed.
- All results agree remarkably well.
- All options meet the experiment design goal.

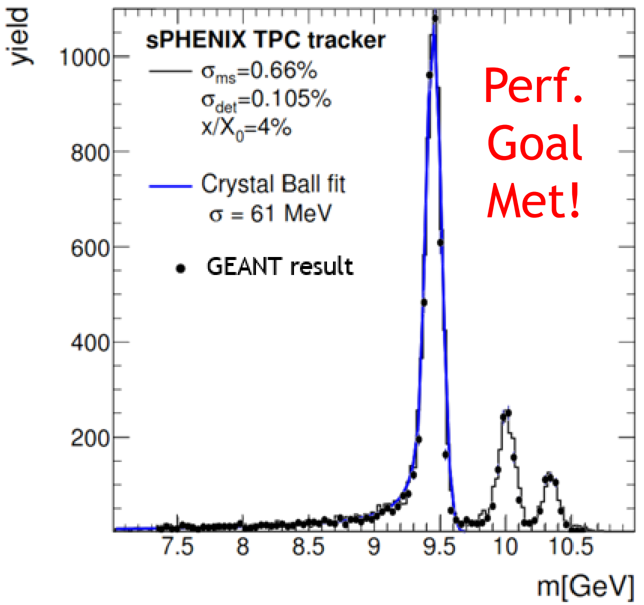
Reference Design



Hybrid: Reuse Pixels + TPC

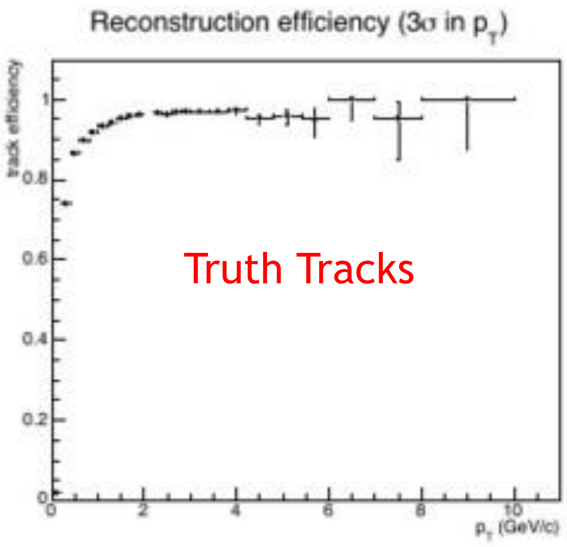


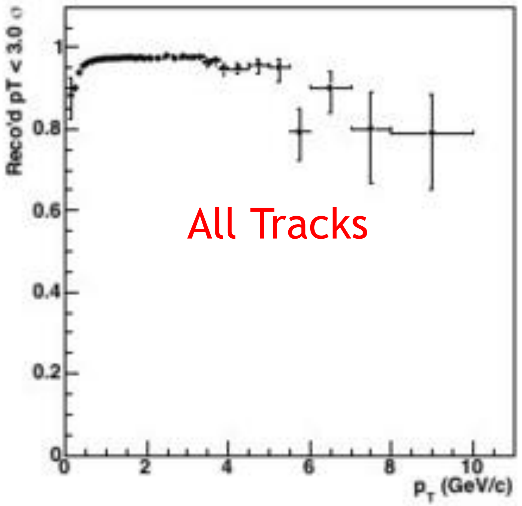




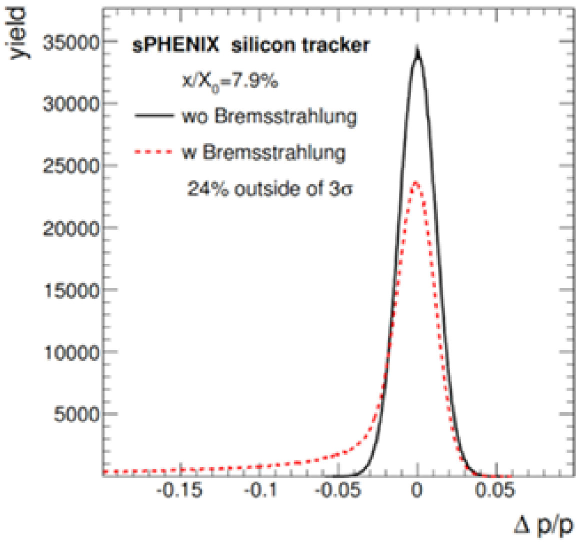
Reconstruction Efficiency

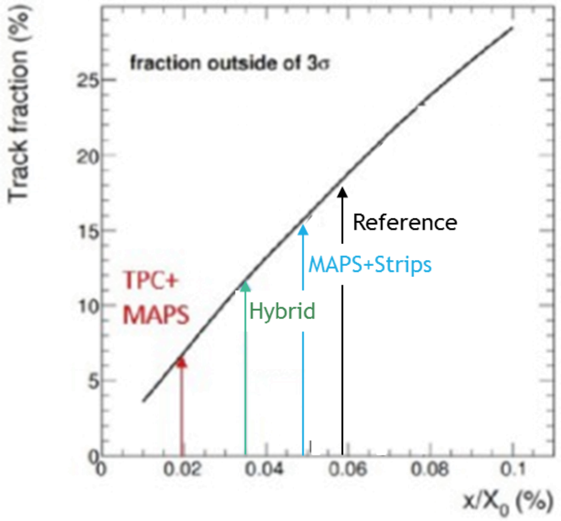
Reference: Central HIJING





Bremsstrahlung-induced Efficiency Losses





- Monte Carlo reconstruction of all tracks demonstrates that the reference version performs remarkably well both for single track events and embedded into central HIJING.
- Electron tracks will also suffer Bremsstrahlung losses forcing them outside the 3σ window.
- These losses are tolerable even in the thickest design option.

	Electron Singles (loss/efficiency)	Electron Pairs (loss/efficiency)
Reference	18% / 82%	33% / 67%
Strip + MAPS	16% / 84%	29% / 71%
Hybrid	12% / 88%	23% / 77%
MAPS + TPC	7% / 93%	12% / 88%

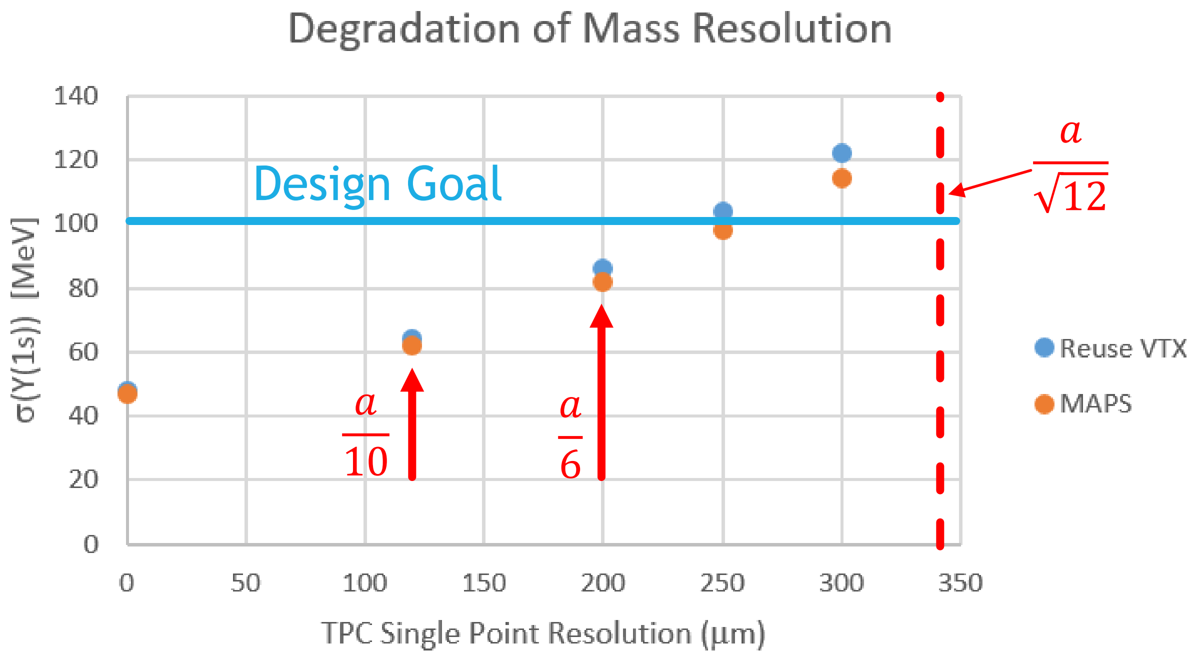
Design Drivers

Reference Option

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18
S0b	4	8.5	58	9.6	240	1.0	0.18
S1a	5	31.0	58	9.6	240	0.6	1.4
S1b	6	34.0	58	9.6	240	0.6	1.4
S2	7	64.0	60	9.6	320	1.0	6.5

- In many ways, a multiple-scattering limited spectrometer is desirable; robust against:
  - Single point resolution.
  - Alignment.
  - Detector “creep”
- The design must maintain detector thickness spec. in the middle layer (dominant contributor to the sagitta determination).
- Mass resolution (currently ~6% better than required) will degrade as $\sqrt{\frac{x}{\chi_0}}$ of the S1 layer and improve as $\frac{1}{R}$ (radius of S2).
- The thickness of S1 determines the over-all size, R, and the cost (≈ R^2).
- We can tolerate a ~12% increase in the S1 thickness in the current design spec.

Hybrid Tracker Option



- The Upsilon mass width for the hybrid setup is influenced by the single point resolution.
- Current calculations assume an RMS resolution of 1/10 the pad size ($\frac{a}{10}$).
- The hybrid system will meet the design goal with an RMS resolution as bad as 250 μm.

Additional Design Drivers for TPC

- The hybrid option will benefit from the development of the ALICE upgrade detector(s).
- The list of considerations necessary to realize the hybrid option is nonetheless significant.
- More detail will be available in the afternoon session.
- Here we summarize some of the challenges facing our design.

	Comment 1	Comment 2
Chevron Pads	Good charge sharing for low diffusion gasses	Asserts a (correctable) diff. non-linearity
GEM gain stages	High rate capable (vs wire chamber)	Gain uniformity and drift; longevity
SAMPA Chip	TPC-specific chip, Continuous readout	ALICE Upgrade
Ion Back Flow	Tunable IBF vs dE/dx resolution	ALICE Upgrade
High Voltage	Known solids capable w/ safety margin.	Solids introduce single point failure.
Diffusion	Small diff improves resol, collection time	Diff assists spreading charge over pads.
Electron v_D	Fast lowers stacked evts; plateau desirable.	Slow lowers "voxel occupancy"
Noble Gas	Ar mix: nice plateau; low field; low ion mobility (therefore lots of space charge)	Ne mix: much higher ion mobility, no plateau, high V_{CM}
dE/dx	Not a driving feature for heavy ion program	Critical for EIC use

More work required to prove viability of hybrid design.

L2 Project Scope

13		1.3.2	⊟ Pixel Detector
14		1.3.2.1	⊞ Pixel Design
29		1.3.2.2	⊞ Pixel Production

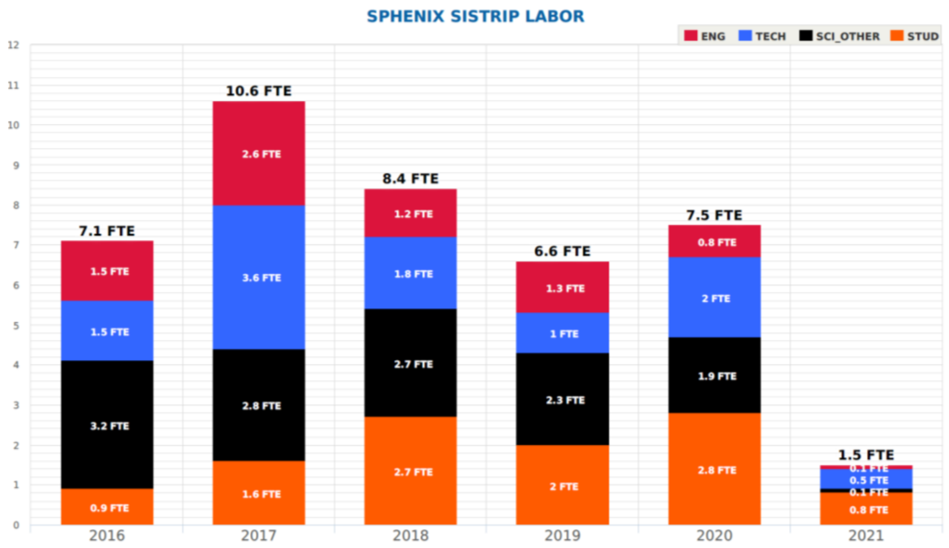
53		1.3.3	⊟ Outer SiStrip Detector
54		1.3.3.1	⊞ Outer SiStrip Design (Mech and system)
71		1.3.3.2	⊞ SiStrip Prototyping
133		1.3.3.3	⊞ Outer SiStrip Production
181		1.3.3.4	⊞ SiStrip Electronics

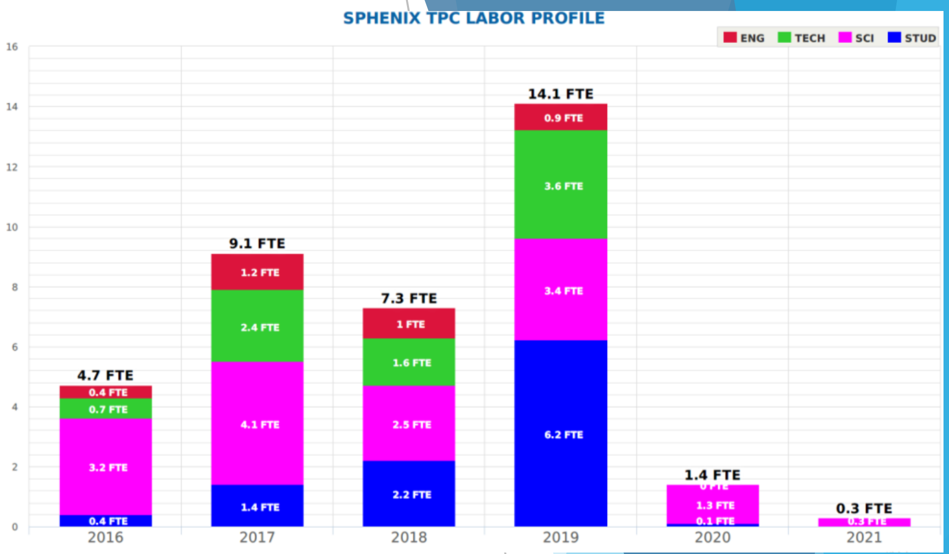
267		1.3.4	⊟ Time Projection Chamber
268		1.3.4.1	⊞ TPC Design
279		1.3.4.2	⊞ TPC Prototype
317		1.3.4.3	⊞ TPC Production
361		1.3.4.4	⊞ TPC Electronics

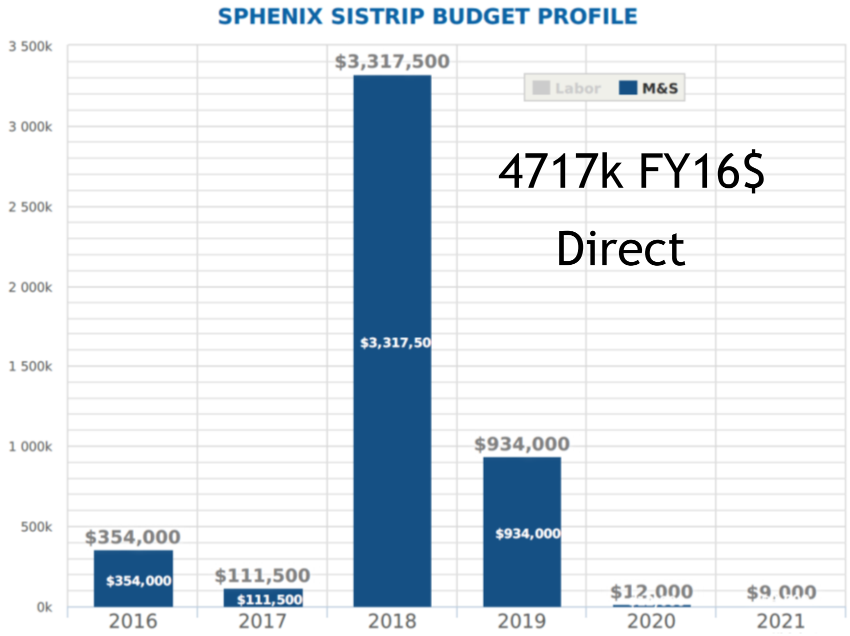
- These charts indicate the L2 items of the project scope for each detector option.

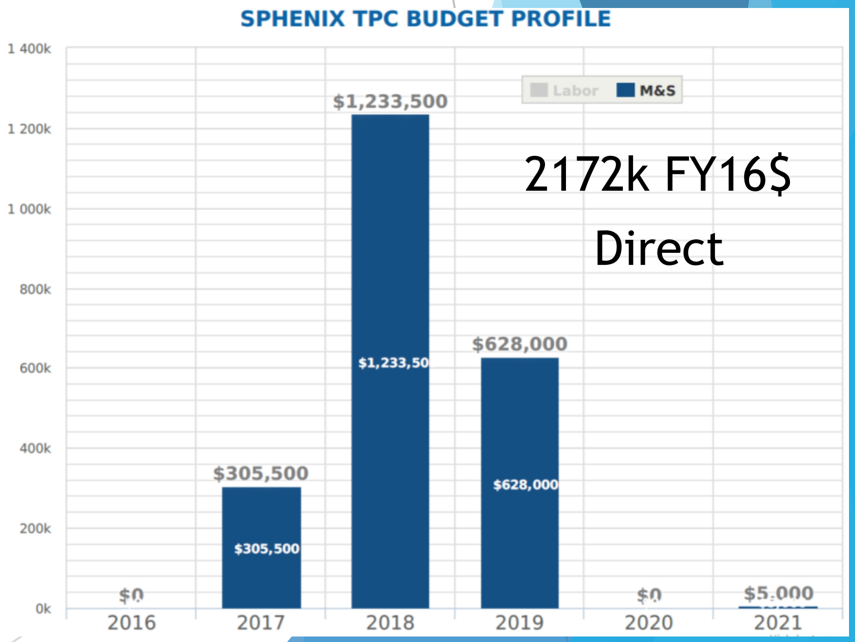
Resource/Cost Drivers

- Costs here are limited to the outer tracker options.
- Details on the inner tracker options will be presented in the afternoon breakout sessions.





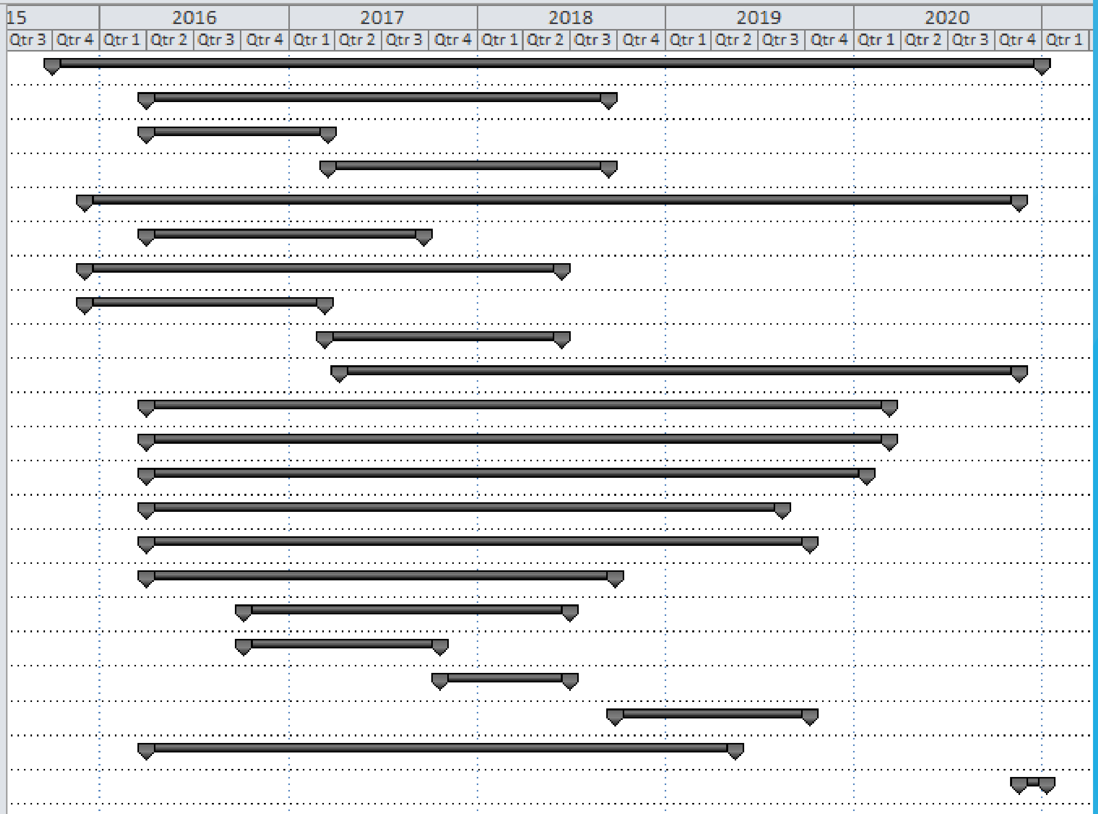




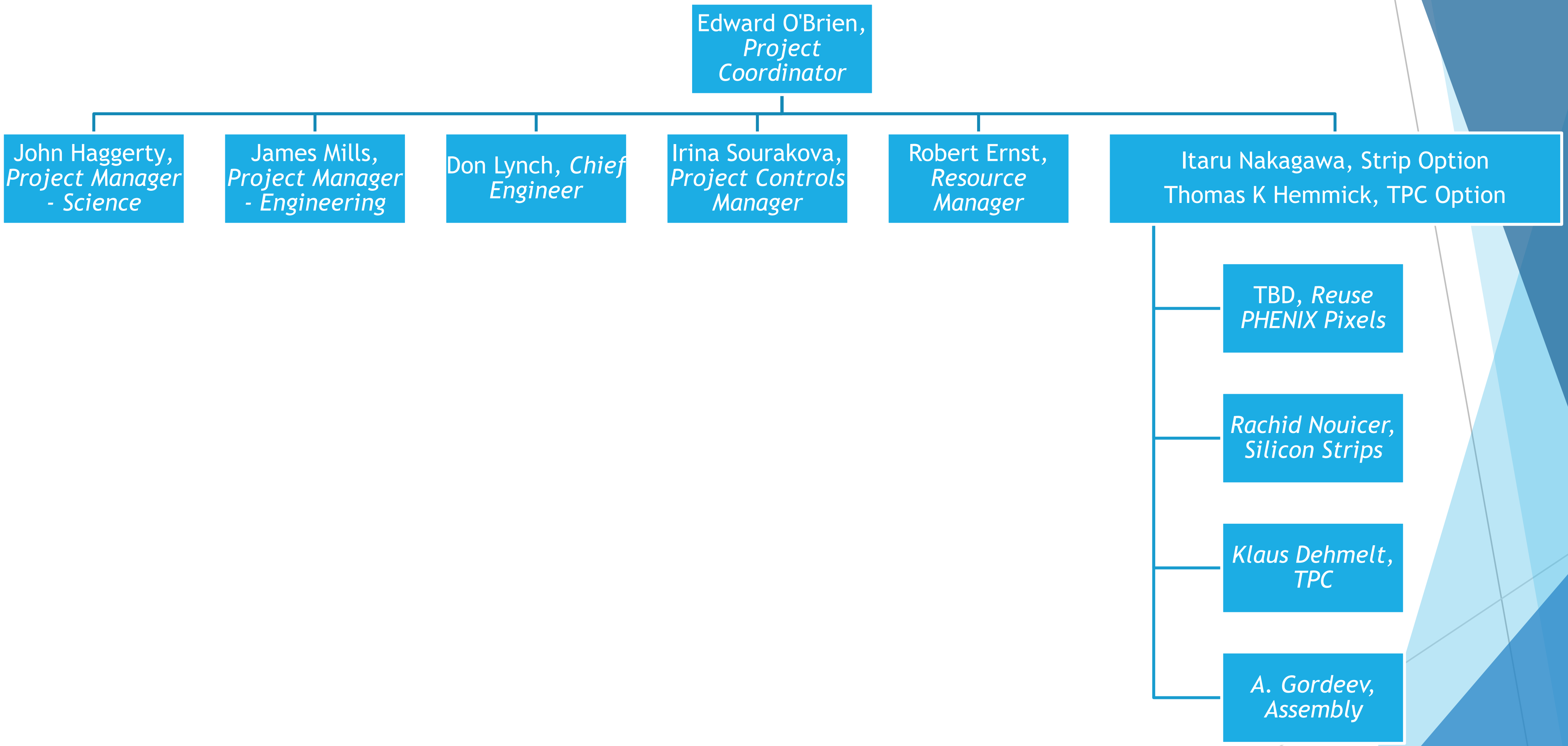
Schedule Drivers

- Technology decision needs to be made sometime in early to mid 2017 though it could easily be driven by a successful receipt of outside funding
- SiStrip: Sensor production and ladder, stave assembly drive the schedule
- TPC: Design and prototyping drive the schedule if one is to be ready to build in Jul 2018.

WBS	Task Name	Duration	Start	Finish
1.3.1	+ Tracker Management	1306 days	Thu 10/1/15	Wed 12/30/20
1.3.2	− Pixel Detector	614 days	Fri 4/1/16	Fri 9/14/18
1.3.2.1	+ Pixel Design	239 days	Fri 4/1/16	Thu 3/16/17
1.3.2.2	+ Pixel Production	375 days	Fri 3/17/17	Fri 9/14/18
1.3.3	− Outer SiStrip Detector	1235 days	Fri 12/4/15	Mon 11/16/20
1.3.3.1	+ Outer SiStrip Design (Mech and system)	369 days	Fri 4/1/16	Wed 9/20/17
1.3.3.2	− SiStrip Prototyping	630 days	Fri 12/4/15	Wed 6/13/18
1.3.3.2.1	+ SiStrip Prototype v2	315 days	Fri 12/4/15	Fri 3/10/17
1.3.3.2.2	+ SiStrip Preproduction Prototype	315 days	Mon 3/13/17	Wed 6/13/18
1.3.3.3	+ Outer SiStrip Production	900 days	Mon 4/10/17	Mon 11/16/20
1.3.3.4	− SiStrip Electronics	981 days	Fri 4/1/16	Tue 3/10/20
1.3.3.4.1	+ SiStrip Sensor ASIC	981 days	Fri 4/1/16	Tue 3/10/20
1.3.3.4.2	+ SiStrip ROC	951 days	Fri 4/1/16	Mon 1/27/20
1.3.3.4.3	+ SiStrip Front End Module	841 days	Fri 4/1/16	Wed 8/14/19
1.3.4	− Time Projection Chamber	880 days	Fri 4/1/16	Wed 10/9/19
1.3.4.1	+ TPC Design	620 days	Fri 4/1/16	Mon 9/24/18
1.3.4.2	− TPC Prototype	432 days	Wed 10/5/16	Fri 6/29/18
1.3.4.2.1	+ TPC Prototype v2	261 days	Wed 10/5/16	Fri 10/20/17
1.3.4.2.2	+ TPC Preproduction Prototype	171 days	Mon 10/23/17	Fri 6/29/18
1.3.4.3	+ TPC Production	260 days	Mon 9/24/18	Wed 10/9/19
1.3.4.4	+ TPC Electronics	780 days	Fri 4/1/16	Thu 5/16/19
1.3.5	+ Final Tracker Assembly/Testing Integration	35 days	Mon 11/16/20	Mon 1/11/21



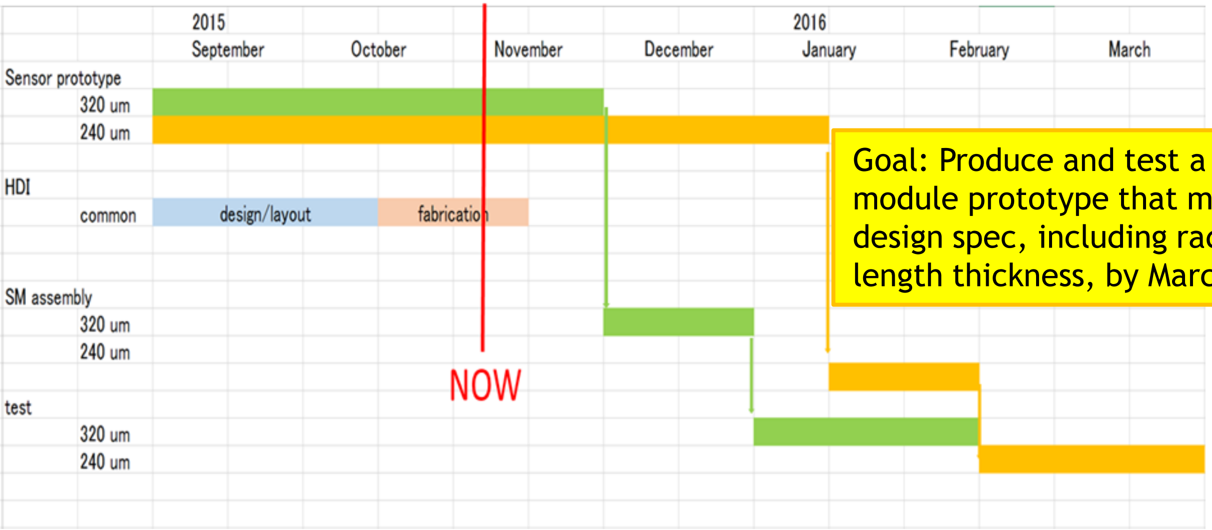
Organization



Organizational Chart depends upon technology choice.

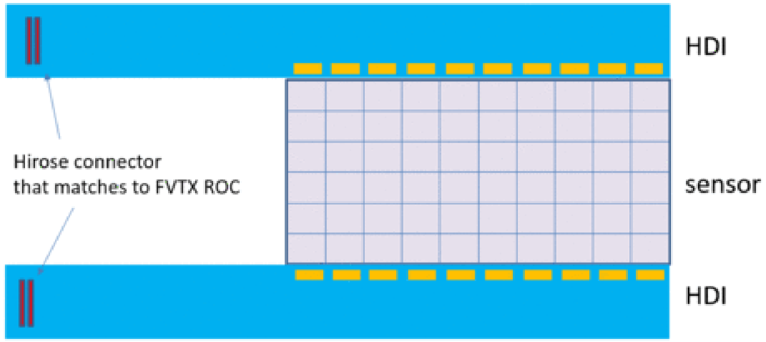
Technical/Project Status

S1 Silicon module prototype



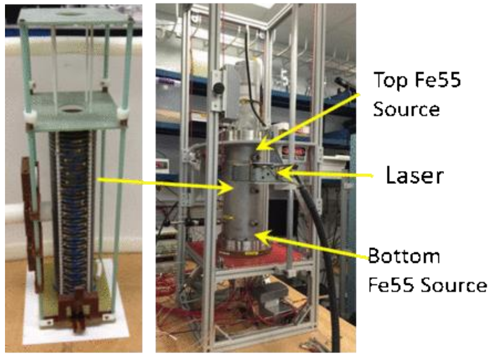
Goal: Produce and test a S1 silicon module prototype that meets the design spec, including radiation length thickness, by March 2016

- Sensor for S2
  - 96 mm x 92.16 mm
  - 320 μm thick
  - AC coupled
  - 60μm x 8mm ministrips
  - 128x24 readout channels
- 5 sensors, March 2015
  - No NG channels or strips
  - Vfd = 50 V
  - Vbreakdown > 250V (>500V for two)
- All 5 sensors are now at BNL for testing

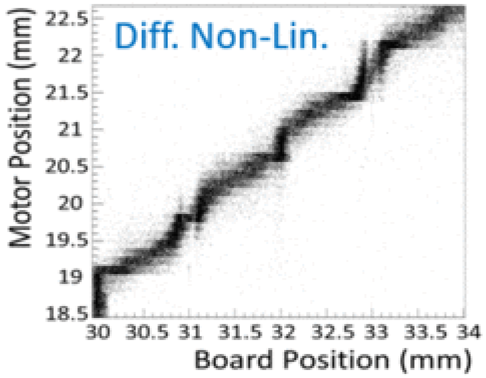


TPC R&D (ongoing from EIC)

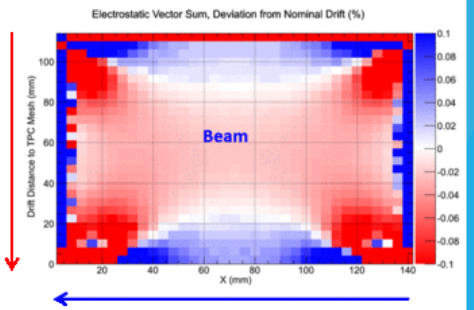
Apparatus



Results



Simulation



- Novel segmentation schemes
- Pad plane response <100 μm w/ 2mm pads.
- Full Gas characterization:
  v_d, charge attachment, ion mobility, avalanche spread.
- Test beam & cosmic tracking.

Issues and Concerns

	Issue/Concern
Technology Downselect	Timeline and Criteria
Reused pixels	Gaps (very small) and dead pixels (lessened using spare ladders).
Strips	Thickness of S1 is critical in determining the over-all size of tracker and thereby the cost.
SAMPA Chip	Timeline for chip production; integration w/ DAQ
Ion Back Flow	Resolution degradation due to space charge distortions.
High Voltage	Single point of failure using solid for HV barrier
TPC Field Map	What is and do we achieve the desired uniformity/measurement
Data Volume for continuous readout.	Sees full collision rate (not just w/in event vertex); needs realistic estimate including effects of noise.
Reconstruction of TPC→Silicon	Requires further simulation of combined performance.

Summary

- Consistent with the charge of maintaining long term viability of the tracking technology we are purposely developing competing alternatives:
  - Inner Vertex Detector
    - Reuse PHENIX pixels
    - MAPS technology
  - Outer Tracker
    - Silicon Strip Detector
    - TPC
- All of these technologies have been shown to meet the physics requirements for heavy ion collisions with varying performance, risk, and utility for longer term use.